CALIBRATING AIMSUN NEXT AND PTV VISSIM FOR THE ASSESSMENT OF TRAFFIC FLOW QUALITY ON TWO- AND THREE-LANE RURAL HIGHWAYS

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ABSTRACT

The German Highway Capacity Manual HBS provides analytical evaluation procedures to assess the quality of service of rural highways. Microscopic traffic flow simulation can be applied as an alternative method if the constraints of the analytical evaluation procedures are not fulfilled.

In this study, practical guidelines and standard parameter sets for the microscopic traffic flow simulation of two- and three-lane rural highways were developed for Aimsun Next and PTV Vissim. For this purpose, artificial rural highway segments, comparable to the models used to develop the procedures in the HBS, are replicated and calibrated based on the speed-flow relationships given in the HBS. The resulting standard parameters can be applied as starting values for calibrating rural highway models in practice.

Both software tools mostly reproduce the speed-flow relationships of the HBS well. The calibration process revealed that the desired speeds, the acceleration behavior and the speed behavior in curves are most relevant for the traffic flow simulation of rural highways in accordance with the analytical evaluation procedure of the HBS. The best results are achieved with low longitudinal gradients and low percentages of heavy vehicles.

The validation of the derived standard parameters with field data showed that the simulation results represent the observed speed-flow relationships well. Deviations between the measured and simulated speeds mainly result from local influences, particularly speed limits. If these local influences are modeled, the simulation results represent real traffic flow well.

Keywords: Microscopic traffic flow simulation, rural highway, highway calibration, speed-flow diagram, HCM, HBS

INTRODUCTION

Two-lane rural highways account for the highest share of the total road network length in most countries worldwide. They have a single carriageway with two lanes for both driving directions and mainly serve to connect towns and villages. The design and operational characteristics of rural highways, including the cross-section width, the horizontal and vertical alignment, as well as the posted speed limit, usually depend on their function in the highway network and the traffic volume. For highways carrying mainly long-distance traffic and/or high traffic volumes, three-lane cross-sections are increasingly used in many countries to avoid passing maneuvers in the opposing traffic lane and hence improve traffic safety. Three-lane rural highways have alternating secured passing sections in both travel directions (see Figure 1).

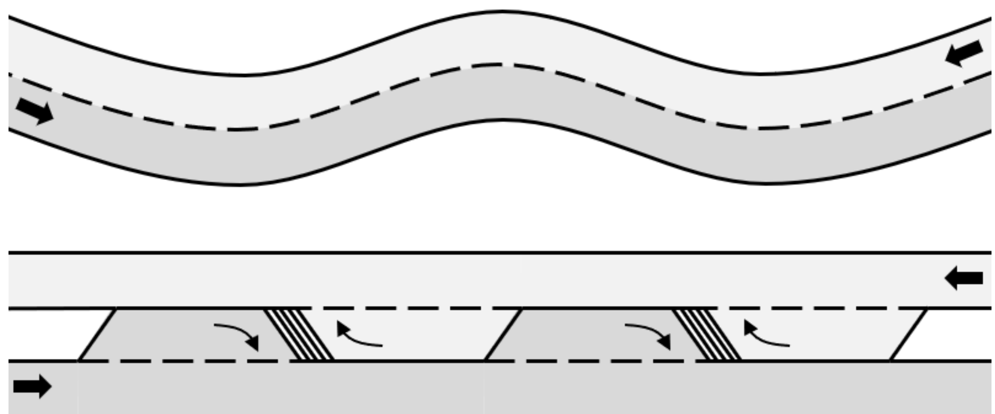

FIGURE 1 : Design of a Two- and Three-lane Rural Highway

Traffic flow on two- and three-lane rural highway segments is mainly characterized by

- the effect of the design parameters (including grade, curvature, and cross-section width) on the drivers' speed behavior,
- the impact of platooning behind slow vehicles, particularly heavy vehicles, and
- the opportunity to pass slow vehicles by using either the opposing lane of two-lane sections (in case of a sufficient sight distance and no opposing vehicles) or the passing lane of three-lane sections.

Based on empirical data from rural roads in Germany as well as microscopic traffic simulation, Brilon and Weiser (*1*) demonstrated that the speed-flow relationship of two-lane highways has a concave shape. A theoretical model by Wu (*2*) also revealed a concave shape of the speed-flow diagram for roads with one lane per direction. This specific characteristic of traffic flow on rural highways can be explained by the impact of heavy vehicles on the average speed of all vehicles. At low volumes, a few slow heavy vehicles in the traffic stream already lead to a significant reduction of the average travel speed. At higher volumes, the further reduction of the average travel speed is smaller because most vehicles already travel in platoons behind heavy vehicles or other slow vehicles.

For the planning of new highways or the enhancement of existing highways, a quality of service assessment is performed. Similar to the U.S. HCM (*3*), the German Highway Capacity Manual HBS (*4*) provides analytical evaluation procedures to estimate the level of service of different types of road facilities. If the constraints of the analytical evaluation procedures are not

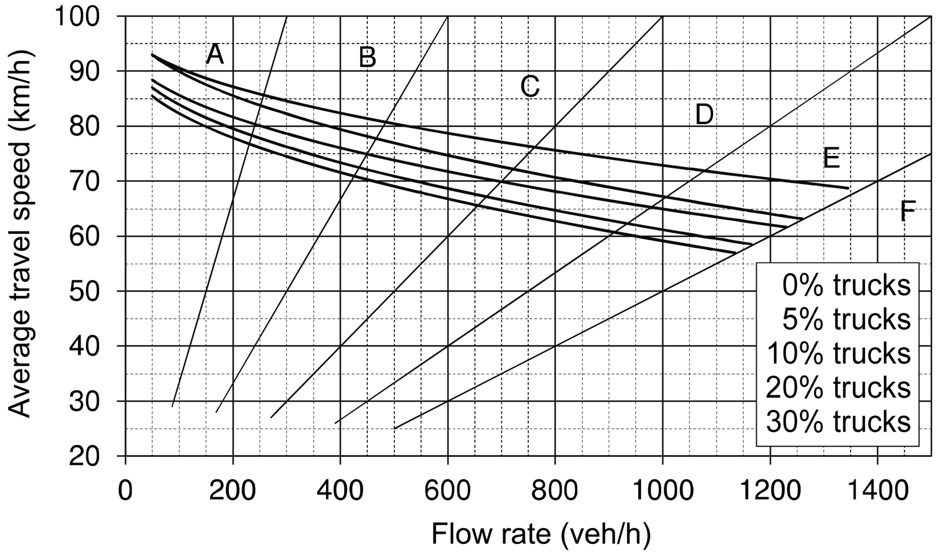

FIGURE 2 : Speed-flow Relationships for Two-lane Highways with Longitudinal Gradient < 3% and Curvature < 50 gon/km According to the German Highway Capacity Manual HBS (*4*)

fulfilled, alternative methods like microscopic traffic flow simulation must be used for the assessment. This is particularly the case if there are strong interactions between traffic flow on adjacent segments or intersections, and hence a holistic traffic flow analysis is required.

In this study, microscopic traffic flow models in Aimsun Next and PTV Vissim are calibrated based on the speed-flow relationships given in the German Highway Capacity Manual HBS. The aim is to develop practical guidelines for performing and evaluating microscopic traffic flow simulations of two- and three-lane rural highways consistent with the HBS assessment procedure. The calibration of the models focuses on consistency with the results of the analytical procedures of the HBS. The objective is to enable a standardized application of microscopic traffic flow simulations for quality of service assessment. Therefore, recommendations on the methodology and standard parameter sets for the simulation tools Aimsun Next and PTV Vissim are derived. Such standard parameter sets and practical guidelines were already developed for multi-lane freeways (*5, 6*). The results are to be incorporated into the German guideline for microscopic traffic flow simulation for both freeways and rural highways.

ASSESSMENT OF RURAL HIGHWAYS ACCORDING TO THE GERMAN HIGHWAY CAPACITY MANUAL

The procedure of the German Highway Capacity Manual HBS (*4*) for the assessment of traffic flow quality on rural highways is applicable to two- and three-lane highways with single carriageways as well as four-lane highways with separated carriageways for each direction. The traffic density per lane is used as the measure of effectiveness. This traffic density is a fictitious value as it is calculated as the ratio of the total traffic volume (including heavy vehicles) and the average travel speed of passenger cars only. Different from the assessment methodology for rural highways in the U.S. HCM (*3*), follower density or percent time spent following were not considered as measures of effectiveness in Germany because platooning of vehicles is regarded as an inevitable consequence of traffic flow on a single directional lane. Therefore, traffic flow parameters addressing the platooning of vehicles are not considered to be appropriate measures of highway performance (*1*).

To estimate the traffic density, speed-flow relationships for different geometric and traffic parameters are provided. The geometric parameters that are considered in the HBS procedure for two-lane rural highways are the curvature, measured in gon per kilometer, and the longitudinal gradient in%. Both parameters are binned in four classes each. For three-lane rural highways, only the gradient is considered as an influencing parameter because the curvature of three-lane highways is usually low. Other geometric parameters like the lane width or the lateral clearance are not considered to significantly influence traffic flow as long as the standards of the German Rural Highway Design Guidelines (*7*) are met. To account for the nonlinear influence of heavy vehicles on the average speed, the traffic volumes are not transferred into passenger car units. Instead, different speed-flow relationships are provided for 0, 5, 10, 20, and 30% heavy vehicles. As an example, Figure 2 shows the speed-flow diagram for two-lane rural highways with a longitudinal gradient less than 3% and curvature less than 50 gon/km.

The speed-flow relationships for two- and three-lane highways given in the HBS originate from simulations of artificial highway segments with a simulation tool called LASI. LASI was developed explicitly for modeling traffic flow on single segments of German rural highways, which were calibrated based on field data (*8–10*). The documentation of the simulation tool is available in German, but the tool itself is not accessible and cannot be used for rural highway simulation applications. Hence, there is a need to replicate the HBS speed-flow relationships with modern, available simulation tools.

MODELING RURAL HIGHWAYS IN AIMSUN NEXT AND PTV VISSIM

To simulate traffic flow on rural highways consistent with the HBS assessment procedure, a simulation tool needs to replicate the effects of the longitudinal gradient, curvature, heavy vehicles, and passing maneuvers. Aimsun Next and PTV Vissim were chosen for this study because they are two of the most used commercial software tools on the market, and both contain the necessary components for simulating rural highways. Aimsun Next uses the Gipps car following model (*11*) for traffic flow modeling. For the simulation of rural highways, a model for passing maneuvers in the opposing lane of traffic is included (*12*). PTV Vissim is based on the psycho-physical car following model, according to Wiedemann (*13*). A model for replicating overtaking in the opposing lane of traffic on rural highways is also implemented (*14*). Aimsun Next version 20 and PTV Vissim version 2020 are used in this study.

The HBS assessment procedures are based on the simulation results obtained with the simulation tool LASI. For the simulations with LASI, different artificial highways segments representing typical curvatures and longitudinal gradients in Germany were modeled. To replicate the HBS as accurately as possible, it is useful to model the assumptions made in LASI in Aimsun Next and PTV Vissim. The artificial highway segments and other basic assumptions of LASI are presented in the Section *Simulation Setup*. Section *Calibration* describes how to transfer the individual components to Aimsun Next and PTV Vissim. The calibration results are compared with the HBS speed-flow diagrams in Section *Calibration Results*. Finally, empirical data is used to verify whether the simulation results agree with measured traffic flow on rural highways (Section *Validation with Field Data*).

Literature Review

When microscopic traffic flow simulations are applied for quality of service assessment, the calibration of the models is of great importance.

Research on the simulation of rural highways in Germany had its peak in the 1970s and 1980s. Based on many studies, the simulation tool LASI was developed and used to simulate the speed-flow diagrams in the HBS. LASI 2+1 refers to further development of LASI and is used to model three-lane rural highways. LASI and LASI 2+1 are based on empirical data. (*8–10*)

The TWOPAS (TWO-lane PASsing) microscopic traffic flow model plays an important role in simulating two-lane rural highways (*15, 16*). Initially developed by the Midwest Research Institute between 1971 and 1974, TWOPAS was used in the Highway Capacity Manual 1985 (*17*) to analyze capacity and level of service for two-lane rural highways. TWOPAS has been updated several times since then to include the ability to simulate passing sections, longitudinal gradients, and short four-lane sections. TWOPAS is used in some research studies on rural highways. (*18–20*)

Bessa et al. (*21*) generated "Percent-time-spent-following" (PTSF) from simulations with the simulation tool CORSIM. PTSF is an evaluation parameter of the design procedure for rural roads of the U.S. HCM. Caliendo and De Guglielmo (*22*) used microscopic traffic flow simulations in Aimsun Next to study speeds in the transition zone between rural roads and populated areas. Munehiro et al. (*23*) dealt with 2+1 rural roads in snowy regions of Japan using the SIM-R simulation tool. Cafiso et al. (*24*) evaluated traffic safety of three-lane rural highways using vehicle trajectories from microscopic traffic flow simulations in PTV Vissim. Romana et al. (*25*) analyzed existing research on the use of rural 2+1 highways with 2+1.

Simulation Setup

Based on the information available on LASI, models comparable to those used to develop the procedures in the HBS at that time were built. The artificial highway segments include four two-lane rural highways representing different curvatures and one three-lane rural highway segment.

The two-lane models represent a change of angle of 25 gon/km (2 curves with 450 m radius), 75 gon/km (6 curves with 350 m radius), 125 gon/km (9 curves with 200 m radius), and 200 gon/km (12 curves with 160 m radius). They have the following characteristics:

- road length of 4 km to evaluate
- additional one kilometer preceding and subsequent road length
- different longitudinal gradients over the entire segments: 1%, 3%, 4%, and 5%
- vehicle input starting at 50 and reaching a maximum of 1200 vehicles per hour, with an increase of 50 vehicles per hour per direction every hour (identical traffic volume in both directions)
- different percentages of heavy vehicles: 0%, 5%, and 20%

The three-lane model has the following properties:

- no curves
- four sections of 1.2 km each with alternating passing sections (see Figure 1)
- additional 500 m preceding and subsequent road length
- vehicle input starting at 200 and reaching a maximum of 1550 vehicles per hour, with an increase of 150 vehicles per hour per direction every hour
- different longitudinal gradients over the entire segments: 2.5%, 5%, 7%, and 8%
- different percentages of heavy vehicles: 0%, 5%, and 20%

These artificial segments were modeled in both simulation tools. Based on these models, the characteristics of rural highway traffic were calibrated in several steps to investigate the corresponding effects on the simulation results. The calibration target is to reproduce the speed-flow relationships given in the HBS.

Calibration

Implementing the components of rural highways is partly done differently in Aimsun Next and PTV Vissim. In the calibration steps, trade-offs were made between the available information about the former rural highway simulations, the modeling possibilities in the software tools, reasonable simulation results, and usability.

Model Setup

The longitudinal gradient is defined in Aimsun Next and PTV Vissim as an argument of the modeled section. It affects the traffic flow by reducing the maximum acceleration of each vehicle. We recommend activating the TWOPAS model in Aimsun Next to determine the acceleration on slopes. The TWOPAS model is based on empirical data. It calculates the maximum acceleration of a vehicle on a slope based on the vehicle' speed, the longitudinal gradient, the ratio between weight and power, and the ratio between weight and frontal area of the vehicle (*26*). The activation of the TWOPAS model leads to a significant reduction in car and heavy vehicle speeds due to the longitudinal gradients. In Vissim, the longitudinal gradient has a similar effect. The maximum acceleration is calculated from the slope and the ratio of weight and power.

Traffic volumes are assumed to be equal in both travel directions. In Aimsun Next, traffic volumes and vehicle compositions are set using OD matrices separately for cars and heavy vehicles. In PTV Vissim, vehicle inputs and static vehicle routes are created for both travel directions.

In both software tools, the distribution of the vehicle lengths has little influence on the simulation results. Therefore, in general, the default settings can be used.

For the evaluation of each calibration step, three simulation runs are performed. Due to the low stochastic variability (almost exclusively free driving or following), the long distance and the long simulation time, very stable results are obtained after only three simulation runs. The results of individual simulation runs hardly differ from each other.

Speed Behavior in Curves

The curvature of a road is represented by its geometry. However, this geometry does not affect the drivers' behavior in both simulation tools. Instead, the maximum speed in curves can be reduced in Aimsun Next. In PTV Vissim, the desired speed distributions can be adjusted by modeling reduced speed areas in curves. It is assumed that vehicles decelerate before a curve, drive through the curve at their reduced curve speed, and then accelerate again to their original desired speed if the traffic situation permits this. The length of the reduced speed area depends on a vehicle's safety need, the angle change, and the curve's radius.

Desired Speed Distributions

The desired speed distributions are modeled separately for cars and heavy vehicles. On two-lane rural highways, the desired speeds depend on the radius of the curves (see Figure 3). For three-lane rural highways, reduced desired speed distributions for cars are defined for segments with longitudinal gradients. Based on empirical data, passenger cars are assumed to drive slower on segments with slopes, although it is not due to a lack of engine power.

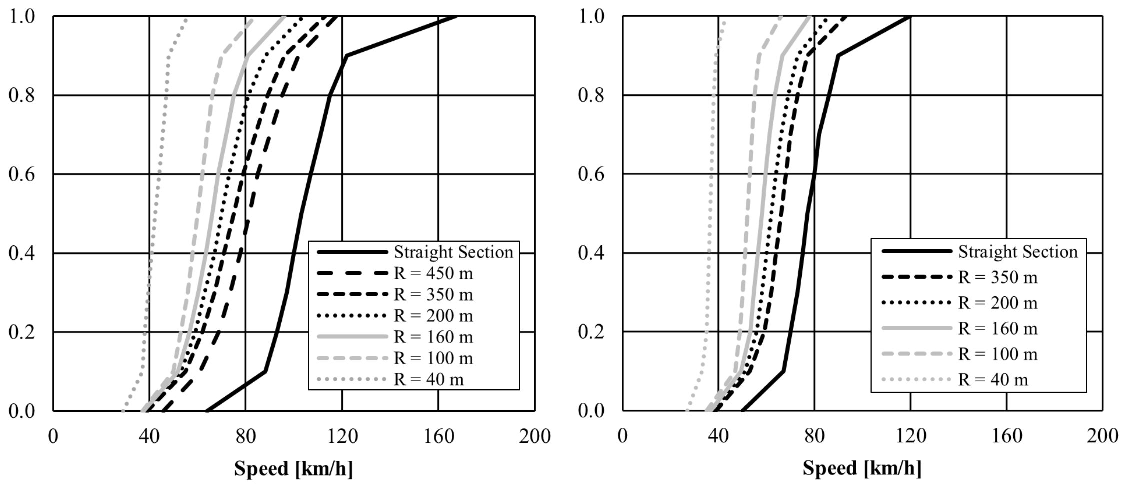

FIGURE 3 : Desired Speed Distributions for Cars (left) and Heavy Vehicles (right) on Two-lane Highways

In Aimsun, each vehicle is assigned a maximum desired speed and a speed acceptance, which remain unchanged throughout a vehicle's lifetime. Maximum speeds are defined for each section and they are multiplied by the individual speed acceptance for each vehicle. The desired speed is the minimum of the maximum desired speed and the accepted section speed for each vehicle. To replicate lower desired speeds in curves and on slopes, the maximum speed on the respective section is reduced.

In PTV Vissim, desired speed decisions or reduced speed areas are created at locations where desired speeds change due to curves or longitudinal gradients. The vehicles are individually assigned a new desired speed from the corresponding distribution at each desired speed decision or reduced speed area.

Driving Behavior

The driving behavior in LASI is based on Wiedemann 74 (*13*) car following model. Cars and heavy vehicles have separate driving behavior.

In both software tools, vehicle classes with different driving behavior can be created for cars and heavy vehicles. In Aimsun Next, the default parameter values of the Gipps model are applied for the cars and heavy vehicles, which lead to comparable results. In PTV Vissim, Wiedemann 74 is selected with the corresponding parameter values as driving behavior (see Table 1).

Maximum Acceleration

In LASI, a distinction is made between a vehicle' maximum acceleration and the driver's desire to accelerate. Cars and heavy vehicles have a separate acceleration behavior.

As the TWOPAS model is activated in Aimsun Next, the parameters *ratio between weight and power* and *ratio between weight and frontal area* influence on the maximum acceleration and thus the speeds of heavy vehicles on slopes. By calibrating these parameters, the resulting TOWPAS maximum accelerations approximate the maximum acceleration distribution from LASI. In PTV Vissim, the functions for maximum and desired acceleration can be transferred from LASI.

TABLE 1 : Parameter Values for the Wiedemann 74 Driving Behavior

Vehicle Class	Veh Class of the Leading Vehicle	W74ax	W74bxAdd	W74bxMult	IncrsAccel
Two-lane Rural Highway					
Car	Car	2.0	2.0	5.00	100 %
	Heavy Vehicles			4.00	
Heavy Vehicles	Car	2.0	2.0	5.80	100 %
	Heavy Vehicles			5.00	
Three-lane Rural Highways					
Car	Car	2.0	0.8	2.00	100 %
	Heavy Vehicles			1.60	
Heavy Vehicles	Car	2.0	0.8	2.32	100 %
	Heavy Vehicles			2.00	

Overtaking

On two-lane rural highways, overtaking is possible in the opposing lane. The overtaking model distinguishes between a overtaking desire and the final overtaking decision. In addition, the visibility in a curve is decisive for the actual feasibility of an overtaking maneuver.

The following parameter values lead to a plausible overtaking behavior in Aimsun Next:

- The *visibility distance* should be selected depending on the length of the overtaking section. A visibility distance of 800 m is set if the visibility is clear.
- The *visibility factor* is 1.0.
- The *overtaking speed enhancement factor* is 1.2.
- Overtaking maneuvers should not be possible in curves.
- Heavy hehicle overtaking maneuvers should be prevented in the simulation. For this purpose, the *safety margin for the overtaking maneuver* for the vehicle type heavy vehicle is increased significantly (μ = 150 s, σ = 3 s) to discourage heavy vehicles from overtaking.

The following parameter values lead to a plausible overtaking behavior in PTV Vissim:

- The *look ahead distance* should be selected depending on the length of the overtaking section. A look ahead distance of 800 m is set if the visibility is clear.
- The *overtaking speed factor* is 1.2.
- The *assumed speed of oncoming traffic* is 120 km/h.
- Overtaking maneuvers should not be possible in curves.
- The *lane change distance* of the connector at the end of an overtaking section should be 200 m.
- Heavy vehicle overtaking maneuvers should be prevented in the simulation. For this purpose, the opposing lane is blocked for heavy vehicles.
- The factor for *reduced safety distance* is 0.3.

When evaluating overtaking maneuvers, it should be ensured that aborted overtaking maneuvers are not included in the overtaking rate.

On three-lane rural highways, overtaking is possible in secured passing sections. LASI defines behavior as follows: The desired speed of an overtaking vehicle increases by 3 m/s during the overtaking process. 300 m before the end of the passing section, a lane change request to the right is triggered and carried out if possible. If a vehicle has not carried out this lane change up to 80 m before the end of the passing section, it may go below the defined minimum following distance in order to enter a smaller gap. Overtaking on two-lane sections adjusts well in Aimsun Next and PTV Vissim without further calibration. Only overtaking for heavy vehicles must be prevented.

This is achieved in Aimsun Next by reducing the *Overtake Speed Threshold* to a value of 20%. In PTV Vissim, the *slow lane rule* is activated on the two-lane sections of three-lane highways. The *lane change distance* of the connector at the end of an overtaking section is set to 300 m. In addition, the left lane is blocked for heavy vehicles. The factor for *reduced safety distance* is 0.3.

Calibration Results

Highway segments of two- and three-lane rural highways were calibrated in Aimsun Next and PTV Vissim. An assessment of the traffic flow of rural highways using microscopic traffic flow simulations requires determining the same measure of effectiveness as in the analytical evaluation procedure of the HBS, the traffic density per lane. To investigate the accuracy of the calibration, the simulated speed-flow relationships are compared to those given in the HBS. To determine this density, an accurate simulation of the average travel speed of passenger cars is required. The first step is to review the speed-flow diagrams visually. For example, for two-lane rural highways, the characteristic concave shape of the speed-flow diagrams must be replicated.

Additionally, the Root Mean Square Percentage Error (RMSPE) (*27*) is used to evaluate the deviation between the simulation results and the HBS quantitatively. The RMSPE indicates how significant the error is relative to the mean value and is calculated using the following equation.

$$RMSPE = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(\frac{x_n^{sim} - x_n^{obs}}{x_n^{obs}}\right)^2}$$

x_n^{obs} and x_n^{sim} describe the mean travel speed of the passenger cars of the empirical and the simulation data at a particular traffic volume.

Figures 4 and 5 show selected results for two-lane rural highways and Figures 6 and 7 for three-lane rural highways. Overall, the results are very similar for both software tools and show that the speed-flow relationships of the HBS are mostly well reproduced. For a perfect replication, the fitted curve based on the simulation data (dark gray) match precisely the HBS curve (black). The light gray curves show the HBS speed-flow relationships for other percentages of heavy vehicles for comparison (same longitudinal gradient and curvature).

For two-lane rural highways, the simulation results show that the RMSPE is small for the simulations with 0% heavy vehicles and low longitudinal gradient regardless of the curvature (Figures 4 and 5 top). The speed level is slightly higher than in the HBS, but the concave shapes of the speed-flow relationships match. Rural highways with little longitudinal gradient and few heavy vehicles frequently occur in reality and are most relevant. The simulation results deviate more for high percentages of heavy vehicles and high longitudinal gradients (Figures 4 and 5 bottom). The simulated traffic is faster at low traffic volumes, and at high traffic volumes, the simulated traffic is slower than assumed in the HBS. For low traffic volumes, both software tools underestimate the impact of heavy vehicles compared to the HBS. However, it is interesting that both Aimsun Next and PTV Vissim produce very similar results. The calibration steps have shown that overtaking in the oncoming traffic lane only causes a slight increase in average travel speeds. It can therefore be concluded that overtaking does not cause this effect. Unfortunately, this study cannot conclusively clarify where these differences come from. However, rural highways with

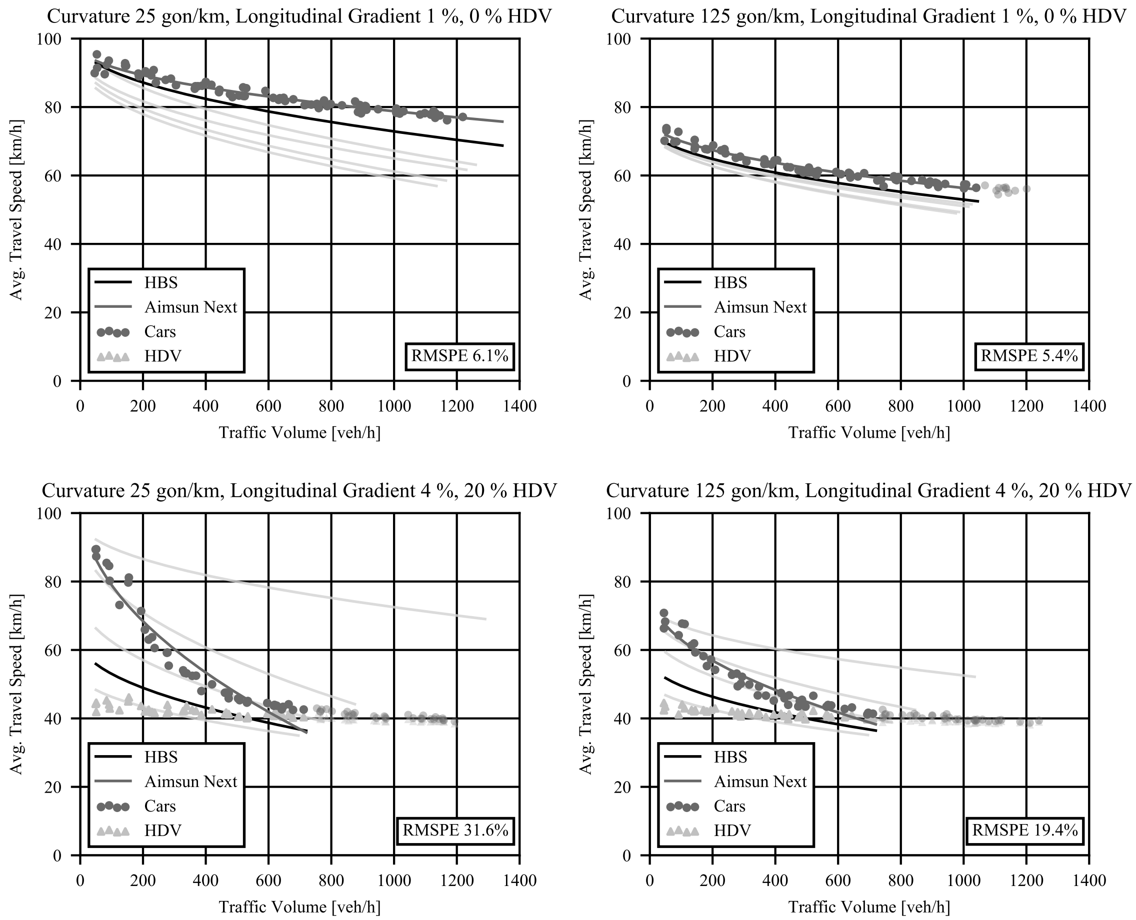

FIGURE 4 : Speed-Flow Diagrams for Cars and Heavy-duty Vehicles on Two-lane Rural Highways in Aimsun Next after Calibration

high longitudinal gradients and high percentages of heavy vehicles rarely occur in reality and are therefore of little relevance in practice.

For three-lane rural highways, single-lane and two-lane (secured passing) sections were evaluated separately. Furthermore, a distinction are made between the first and second single-lane and two-lane sections.

On single-lane sections, the RMSPE is low for simulations without heavy vehicles and little longitudinal gradient. For high longitudinal gradients and high percentages of heavy vehicles, the traffic is increasingly slower in the simulation than assumed in the HBS. The concave shapes correspond to the HBS speed-flow diagrams for all combinations of percentages of heavy vehicles and longitudinal gradients. A comparison between the first and second single-lane sections only shows minimal deviations.

On two-lane passing sections, the RMSPE is consistently low, and the HBS speed-flow relationships are well reproduced. The shapes of the speed-flow diagrams match for all combinations of longitudinal gradient and percentage of heavy vehicles. A comparison between the first and second two-lane sections shows differences. As the percentage of heavy vehicles increases, average passenger car travel speeds increasingly deviate from the HBS. The cars are consistently

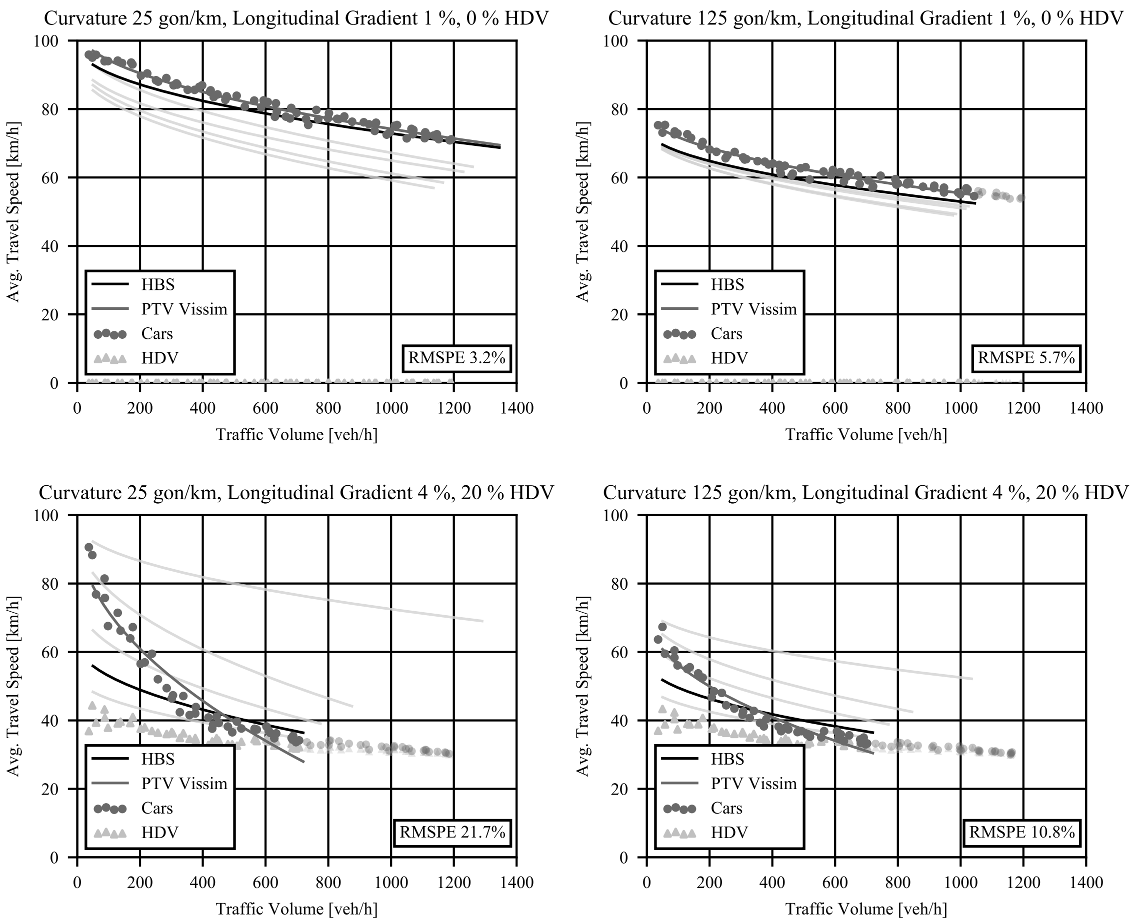

FIGURE 5 : Speed-Flow Diagrams for Cars and Heavy-duty Vehicles on Two-lane Rural Highways in PTV Vissim after Calibration

slower in the second two-lane section than in the first section. The difference is that the single-lane section upstream of the first two-lane passing section is 500 m long and the single-lane section upstream of the second two-lane passing section is 1200 m long. A sensitivity analysis shows that the length of the single-lane section upstream influences the speeds on the following two-lane section. Platooning behind slow vehicles is more advanced on a longer single-lane section. Therefore, the speeds at the beginning of the two-lane section are lower, and accelerating to overtake takes more time. This reduces the average speed on the two-lane section.
Comparing the speed-flow relationships between each calibration step revealed that

- the desired speeds of passenger cars and heavy vehicles,
- the acceleration behavior (mainly of heavy vehicles), and
- the reduced speeds in curves

are the most relevant components for the replication of the HBS speed-flow relationships. The modeling of overtaking maneuvers in the simulation mainly influences the travel speeds on three-lane highways. The calibration results show that the speed-flow relationships of the HBS can be well represented with the developed parameter sets. The question arises, however, whether the simulated travel times also correspond to reality.

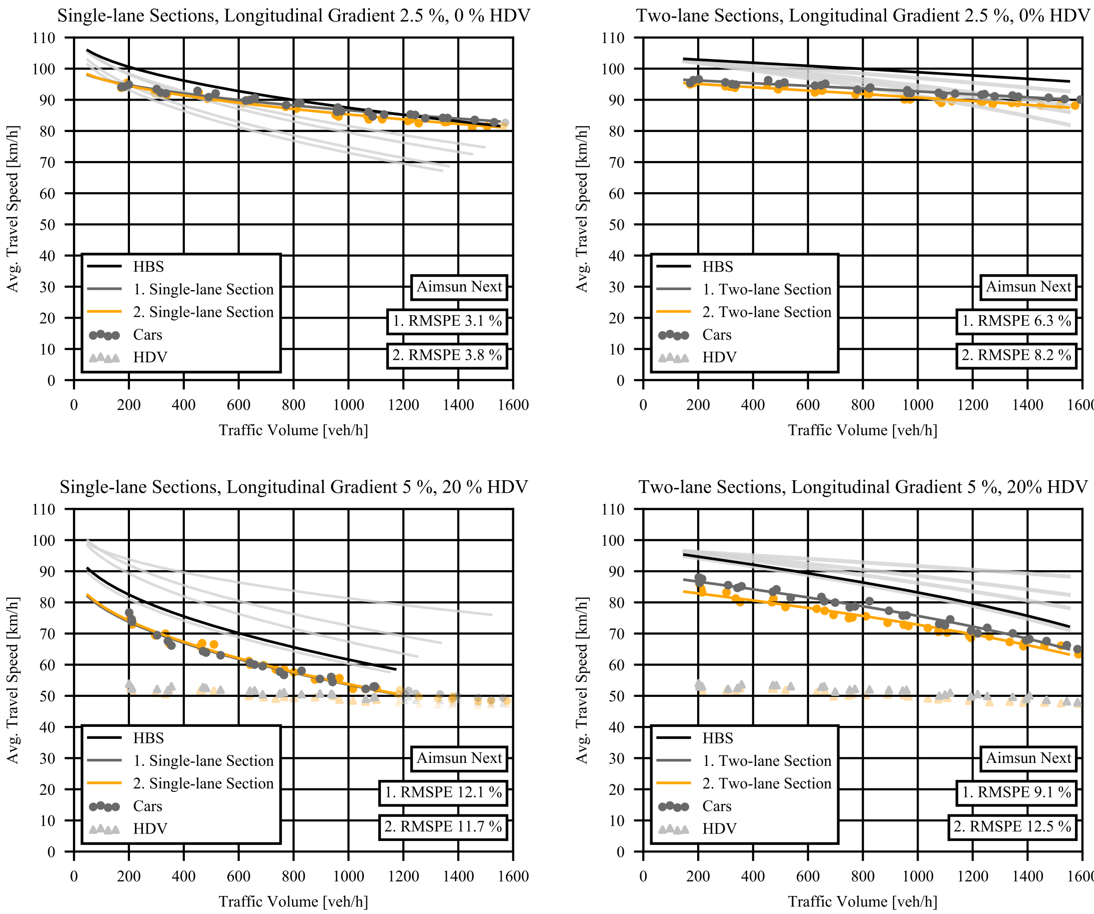

FIGURE 6 : Speed-Flow Diagrams for Cars and Heavy-duty Vehicles on Three-lane Rural Highways in Aimsun Next after Calibration

Validation with Field Data

For validation, the derived standard parameters are used to simulate real rural highway segments. For these rural highways, empirical data are analyzed and compared to the simulation results.

Extensive empirical data are collected for the validation procedure. The measurements cover seven rural highway segments that comply and three rural highway segments that do not comply with the constraints of the HBS. The field data include both two- and three-lane rural highways segments. For all highway segments, speed-flow relationships are observed using local measurements with loop or radar detectors. In addition, travel times on the segments are collected based on bluetooth detectors and automatic number plate recognition.

All segments are replicated in Aimsun Next and PTV Vissim. The horizontal alignments are modeled based on aerial photographs, and the longitudinal gradients are approximated from the elevation data in aerial photographs. For the traffic volumes and percentages of heavy vehicles, the field data (between 6 a.m. and 10 p.m.), aggregated to 5-minute intervals, are used. The simulations have a lead time of 15 minutes and a preceding road segment with a length of 2 km. An investigation on the platoon formation in the simulation showed that platooning behind slow vehicles is completed after 2 km. The preceding road segment is single-lane, level and passing maneuvers

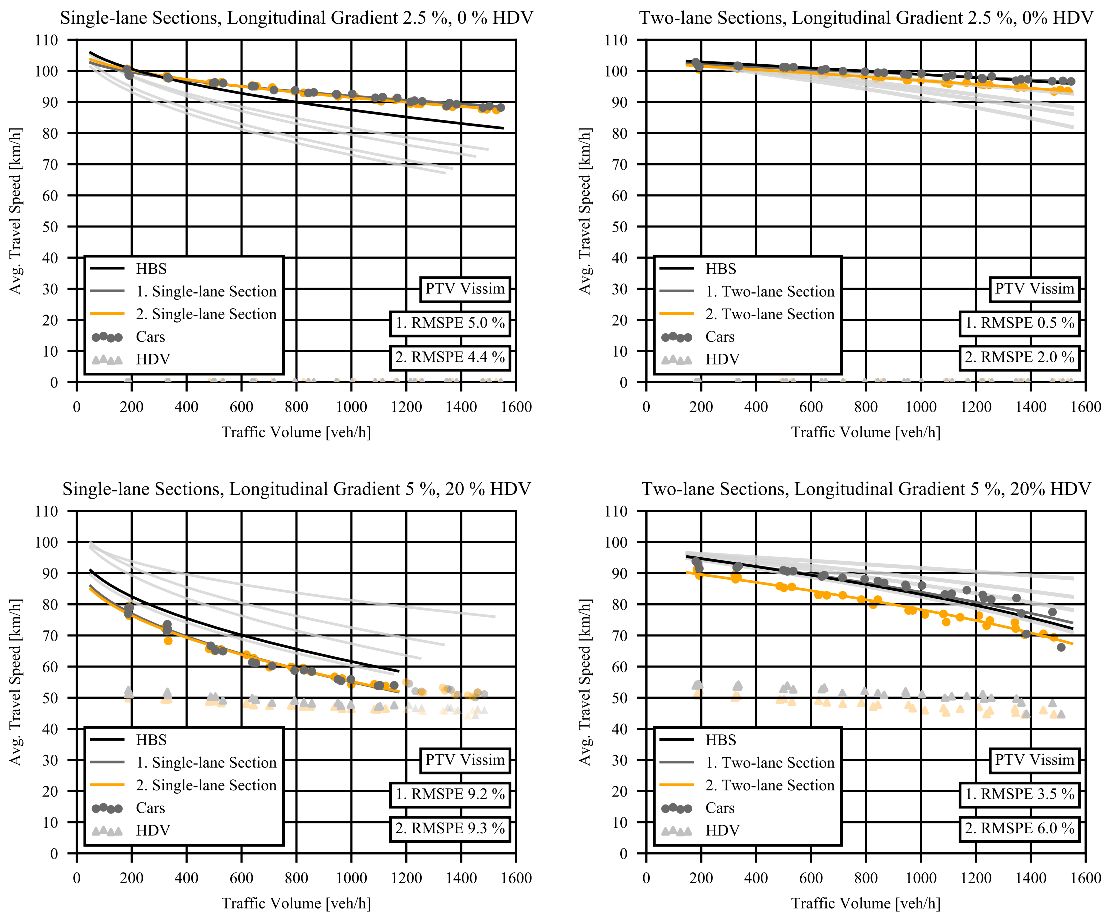

FIGURE 7 : Speed-Flow Diagrams for Cars and Heavy-duty Vehicles on Three-lane Rural Highways in PTV Vissim after Calibration

are prohibited. If a signal-controlled intersection is located upstream of the investigated segment, platooning mainly depends on the signal control. Therefore, signal-controlled intersections are also modeled.

The traffic volume of oncoming traffic significantly affects overtaking opportunities if passing maneuvers in the opposing lane of traffic are allowed. Therefore, both travel directions are modeled for the two-lane segments. The local conditions such as overtaking prohibitions and sight distances are adopted in the models. The standard set of parameters derived in the calibration process is used without any further calibration using the field data. For the evaluation, three simulation runs are performed. The results of individual simulation runs hardly differ from each other.

The measured travel speeds of the passenger cars as well as the simulation based travel speeds are aggregated to 5-minute-intervals. Figures 8 and 9 show selected results for two- and three-lane highways. Comparing the empirical data and the simulation results shows that the simulation can represent the observed speed-flow relationships quite well. The differences between the measured and simulated speeds are noticeable for some segments, but they mainly result from local influences, particularly speed limits. Speed limits are not considered in the methodology of the HBS and are therefore not represented by the standard parameters. By using empirically de-

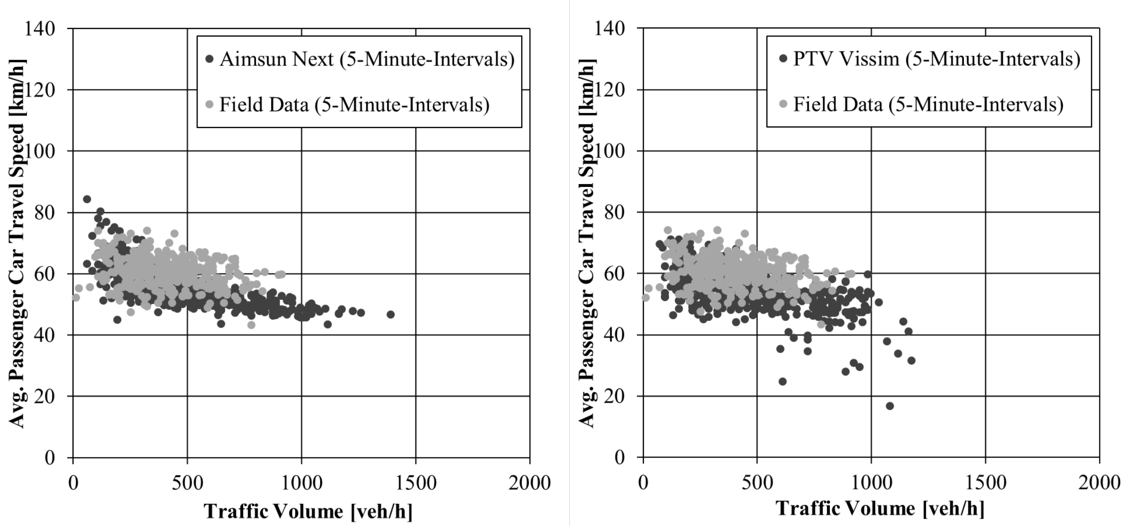

FIGURE 8 : Validation of Two-lane Rural Highway *L138 Duisburg* in Aimsun Next and PTV Vissim

termined desired speed distributions for those segments, the simulation results fit well. The rural highway *L138 Duisburg* has, for example, a speed limit of 70 km/h. By using empirically determined desired speed distributions of the segment under investigation, the simulated speed-flow diagram replicates the field data (see Figure 8). The rural highway *B10 Landau* does not have any local specifics. The simulated speed-flow diagram replicates the field data without any further calibration (see Figure 9).

Even when modeling highway segments that do not comply with the constraints of the HBS, the simulation can represent the real traffic flow quite well. In these cases, too, local influences have to be modeled. For example, two three-lane rural highways with high curvature have been analyzed in this study. Although curves on three-lane highways are not considered in the analytical assessment procedure, it is useful to model the speed behavior in curves in the same way as for two-lane highways.

CONCLUSIONS

In this study, standard parameter sets and recommendations for the microscopic simulation of traffic flow on two- and three-lane rural highways were developed, which can be used for the quality of service assessment of rural highway designs in practice. All simulations were performed for both Aimsun Next and PTV Vissim, and the calibration was based on the speed-flow relationships given in the German Highway Capacity Manual HBS.

Both software tools mostly reproduce the speed-flow relationships of the HBS well. The calibration process revealed that the representation of

- the desired speeds of passenger cars and heavy vehicles,
- the acceleration behavior (mainly of heavy vehicles) and
- the reduced speeds in curves

are most relevant for the traffic flow simulation of rural highways in accordance with the analytical evaluation procedure of the HBS. The best results are achieved with low longitudinal gradients and low percentages of heavy vehicles. The simulations show that both software tools underestimate

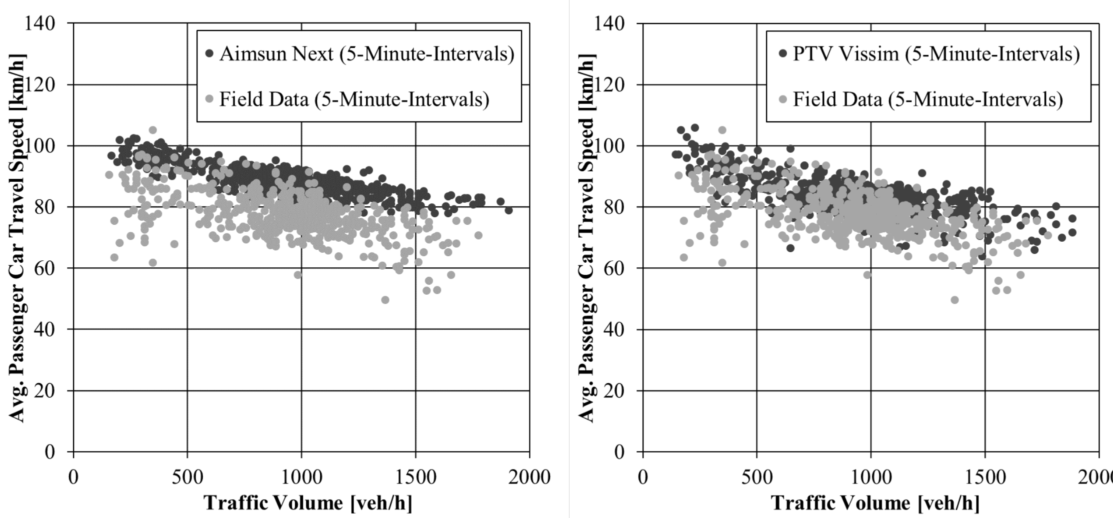

FIGURE 9 : Validation of the Three-lane Rural Highway *B10 Landau* in Aimsun Next and PTV Vissim

the impact of heavy vehicles compared to the HBS.

Validation of the derived standard parameters with field data showed that the simulation results represent the observed speed-flow relationships well. Deviations between the measured and simulated speeds mainly result from local influences, particularly speed limits. If these local influences are modeled in the simulation, the simulation results represent real traffic flow well. These results apply both for two- and three-lane rural highways that do and those that do not comply with the constraints of the analytical assessment procedure.

The results of this study enable a standardized application of microscopic traffic flow simulations for the quality of service assessment of rural highways. The standard parameters can be applied as starting values for the calibration, but they do not replace the calibration process. The results are to be incorporated into the German guideline for microscopic traffic flow simulation.

In the calibration steps, trade-offs were made between the available information from the artificial rural highway simulations, the modeling possibilities in the software tools, reasonable simulation results, and usability. At some points, it can be questioned whether the assumptions from the HBS still reflect today's rural highway traffic. One example is the modeling of heavy vehicles in the simulation, which could be subject to further research. Updated values for the maximum acceleration of heavy vehicles might reveal that the influence of the gradient on traffic flow performance is less than assumed so far. Furthermore, the speed behavior in curves needs to be explicitly adjusted by the user in both software tools. Development towards the incorporation of the influence of road design parameters into the driver behavior model would be useful. In addition, the overtaking models in Aimsun Next and PTV Vissim could be revised. Both simulation tools do not include the acceleration of the leading vehicle in the overtaking decision. In the simulations, this problem causes overtaking maneuvers to be aborted because the maneuvers cannot be completed due to the leading vehicle accelerating (for example, behind a curve).

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AUTHOR CONTRIBUTION

The authors confirm contribution to the paper as follows: study conception and design: C.M. Weyland, H.S. Buck, J. Geistefeldt, P. Vortisch; literature review: C.M. Weyland, J. Geistefeldt; modeling and simulation: C.M. Weyland, H.S. Buck; analysis and interpretation of results: C.M. Weyland, H.S. Buck, J. Geistefeldt; draft manuscript preparation: C.M. Weyland, H.S. Buck, J. Geistefeldt, P. Vortisch. All authors reviewed the results and approved the final version of the manuscript.

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